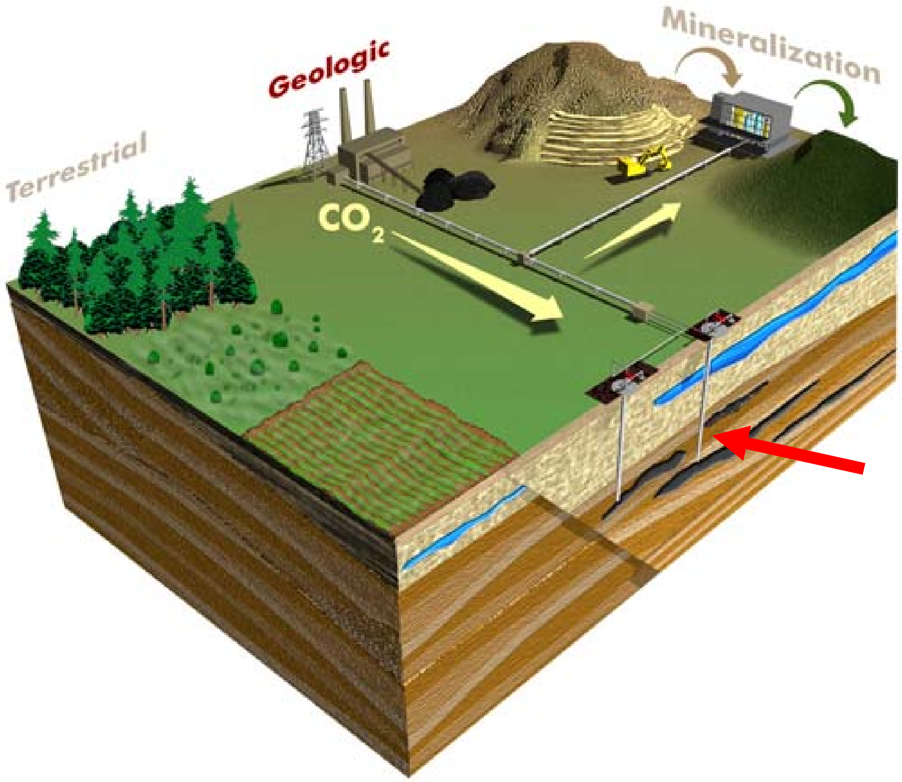
EOR Experience and a Science-Based Treatment of Wellbore Integrity in a CO_2 Storage System



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Sample Recovery; Field History

- Pete Hagist, Scott Wehner (Whiting)
- Mike Raines (PetroSource)
- Mike Hirl (KinderMorgan CO_2)

Cement Integrity

- Bill Carey, Peter Lichtner, Marcus Wigand, Steve Chipera, Giday WoldeGabriel
- Brian Strazizar, Barbara Kutchko (NETL)

Science-Based System Modeling

- Rajesh Pawar, Phil Stauffer, Hari Viswanathan, Seth Olsen, John Kaszuba, Gordon Keating, Tom McTighe, Richard Middleton
- Dmitri Kavetski, Mike Celia (Princeton)
- [Howard Herzog (MIT)]
- [Grant Bromhal, Anthony Cugini (NETL)]
- [Stefan Bachu, AEUB]

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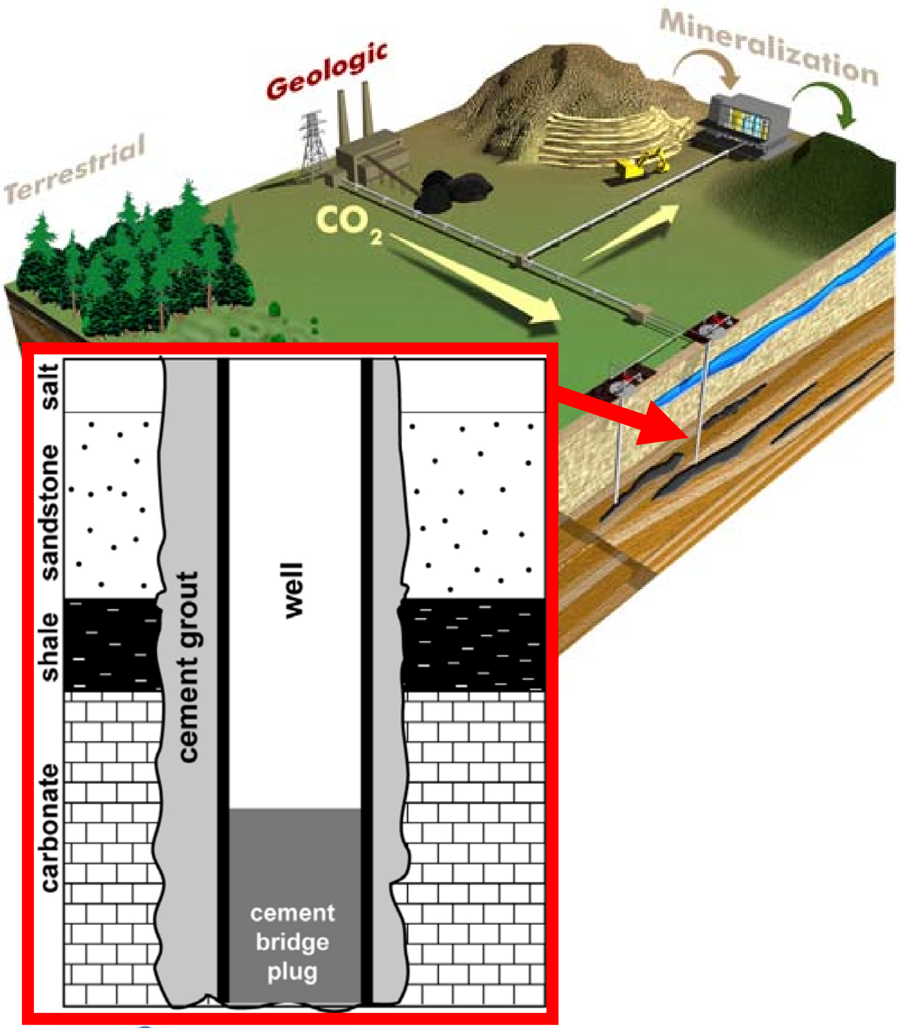
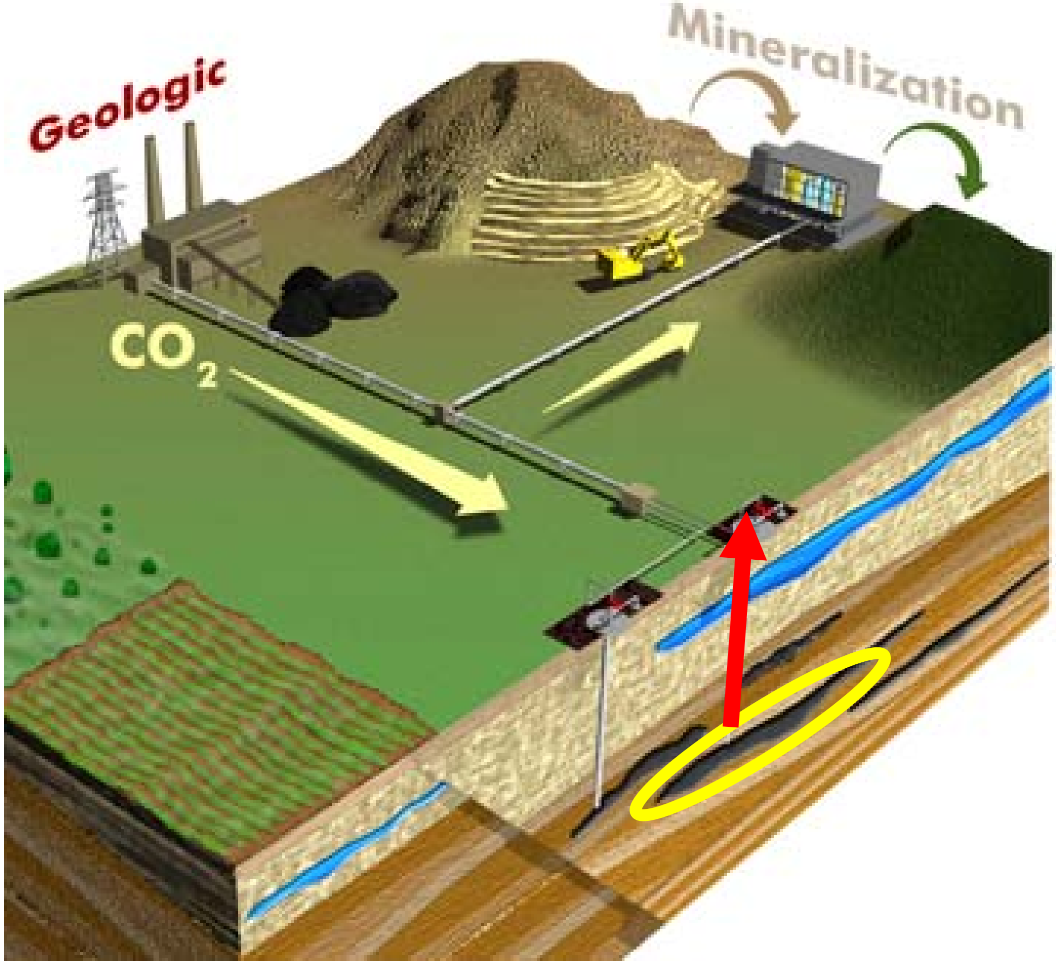
Wellbore integrity is important in long-term CO_2 storage.



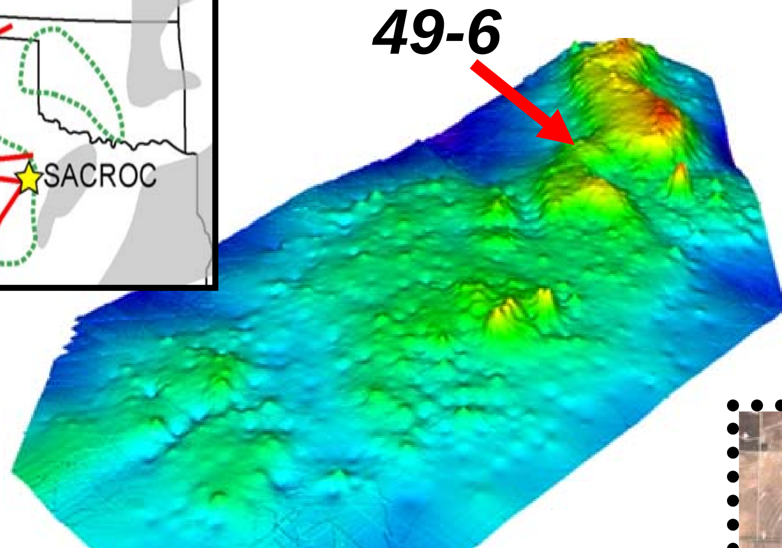
- **Wellbores are typically completed & plugged with portland-based cement**
  - **hydrated portland cements contain calcium hydroxide (a base) and other acid sensitive materials**
- **Portland-based cements can degrade in the presence of CO_2 & water**
  - **CO_2 + water => carbonic acid**
  - **batch experiments suggest rapid degradation of cement by carbonic acid**
- **Integrity of cement has important implications for long-term fate of CO_2**
  - **potential release pathway?**
- **EOR sites provide direct information on cement integrity in the field**
  - **samples allow development and validation of our predictions**

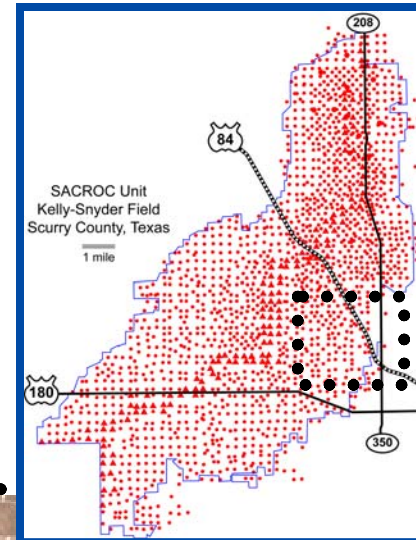
Wellbores are potential release pathways from the storage reservoir to other parts of the system.



- Potential conduit past seal
  - To surface, other subsurface reservoirs, …
- Potential for interactions with numerous wellbores
  - Deep and shallow wells
  - Princeton analytical model (e.g., Nordbotten, Celia, Bachu, 2004)
- Must scale fundamental physics and chemistry to system level
  - Must know brine-CO_2-cement interaction mechanisms, including impact on permeability

CO_2-EOR operations routinely utilize wellbore technology to place (and to contain) fluids within the reservoir.





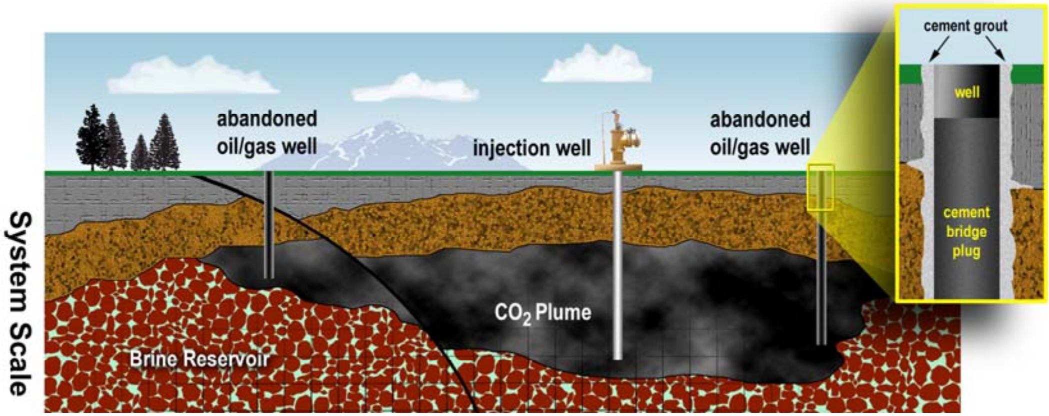
SACROC is one of several industrial-scale examples in the Permian Basin

- **~13.5 million tonnes of CO_2/yr injected**
- **(~6-7 million t/yr of new CO_2)**
- **~ 70 million tonnes CO_2 accumulated (>30 million tonnes anthropogenic)**
- **CO_2 injection since 1972**

Carey et al., 2007

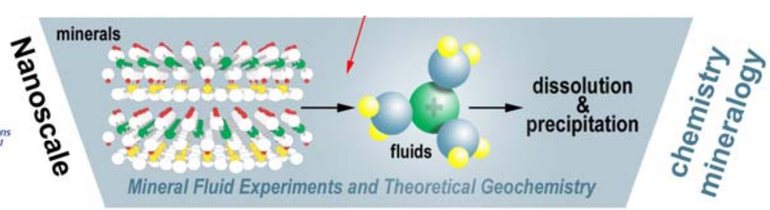
Upscaling from molecular processes to system behavior is grand challenge for predicting long-term fate of CO_2.

Predicting and Engineering Natural Systems

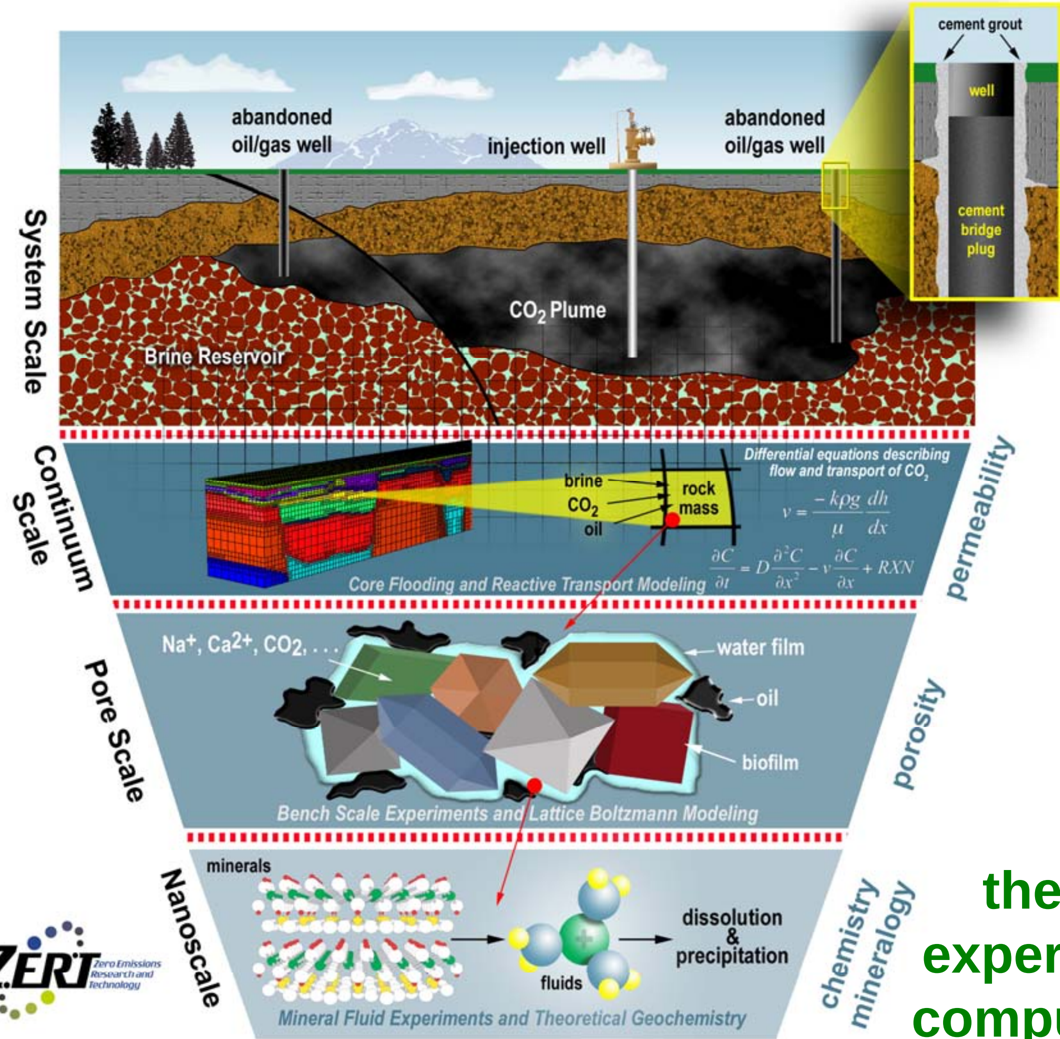


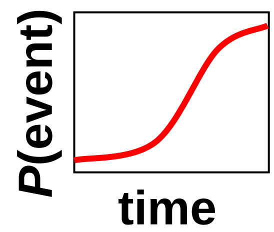
?

- Site specific complexity, heterogeneity, & uncertainty
- Poorly defined phenomena (e.g., hydrogeochemical processes)
- Wide range in length scale (nanoscale processes control reservoir-scale behavior)
- Wide range in time scale (days to millennia)



Science based prediction of natural system performance requires system-level probabilities based on process level phenomena.



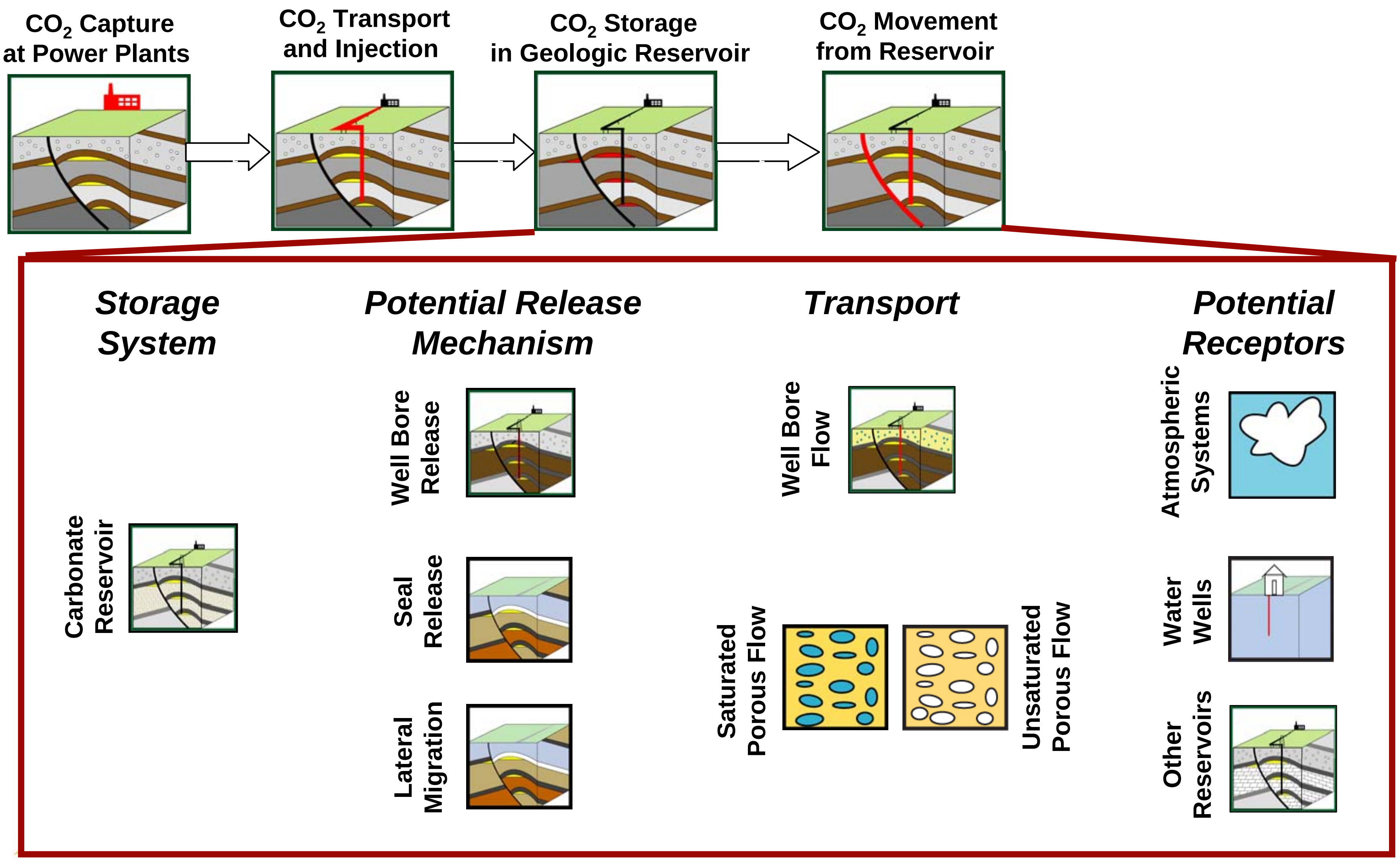


system model (probabilistic)

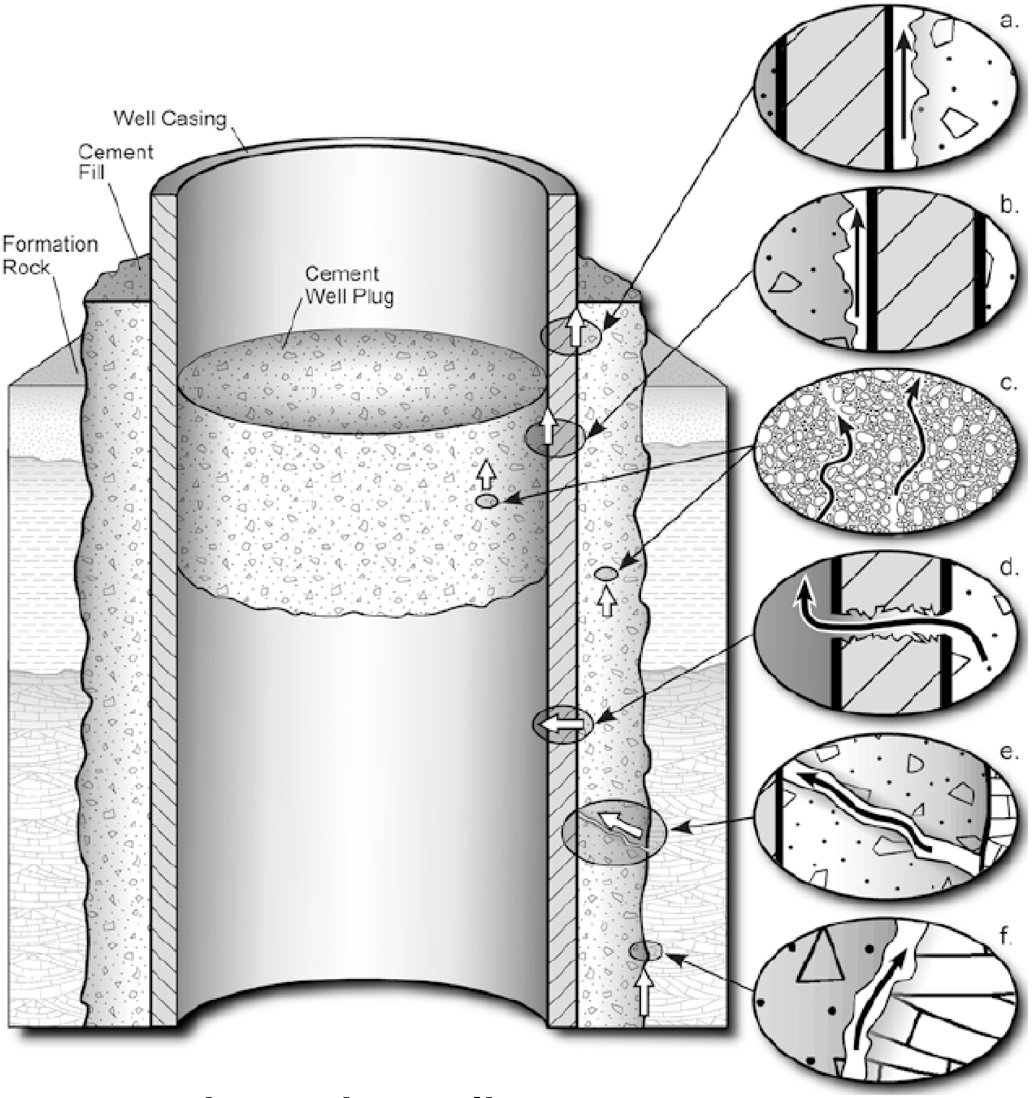
theory, experiment, computation

observation (analog sites)

Preliminary version of CO_2-PENS system model has several modules associated with wellbore release.



Several processes have the potential to contribute to CO_2 release from wellbores.



0. dissolution/corrosion of cement

1. flow between cement & casing (Gasda et al. mechanisms A & B)

2a. diffusion through cement (Gasda et al. mechanism C)

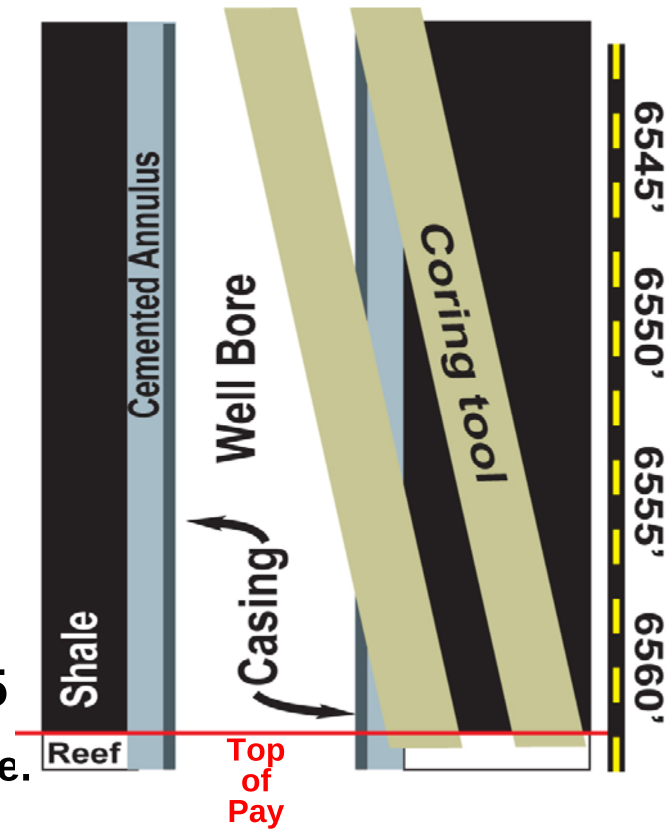
2b. fracture flow through cement (Gasda et al. mechanism E)

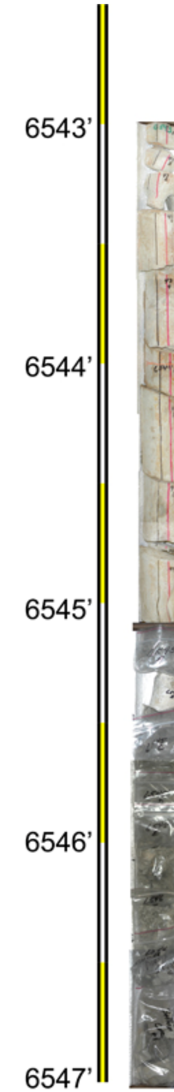
3. flow between cement & shale (Gasda et al. mechanism F)

Gasda, Bachu, Celia, 2004
Princeton CMI

Whipstock drilling at SACROC 49-6 provided recovery of core through cemented annulus to within 12' of top of pay.

- Drilled/completed 1950
- Water flood initiated 1954
- First direct CO_2 exposure 1975
  - 10 yrs as injector; 7 yrs as produce





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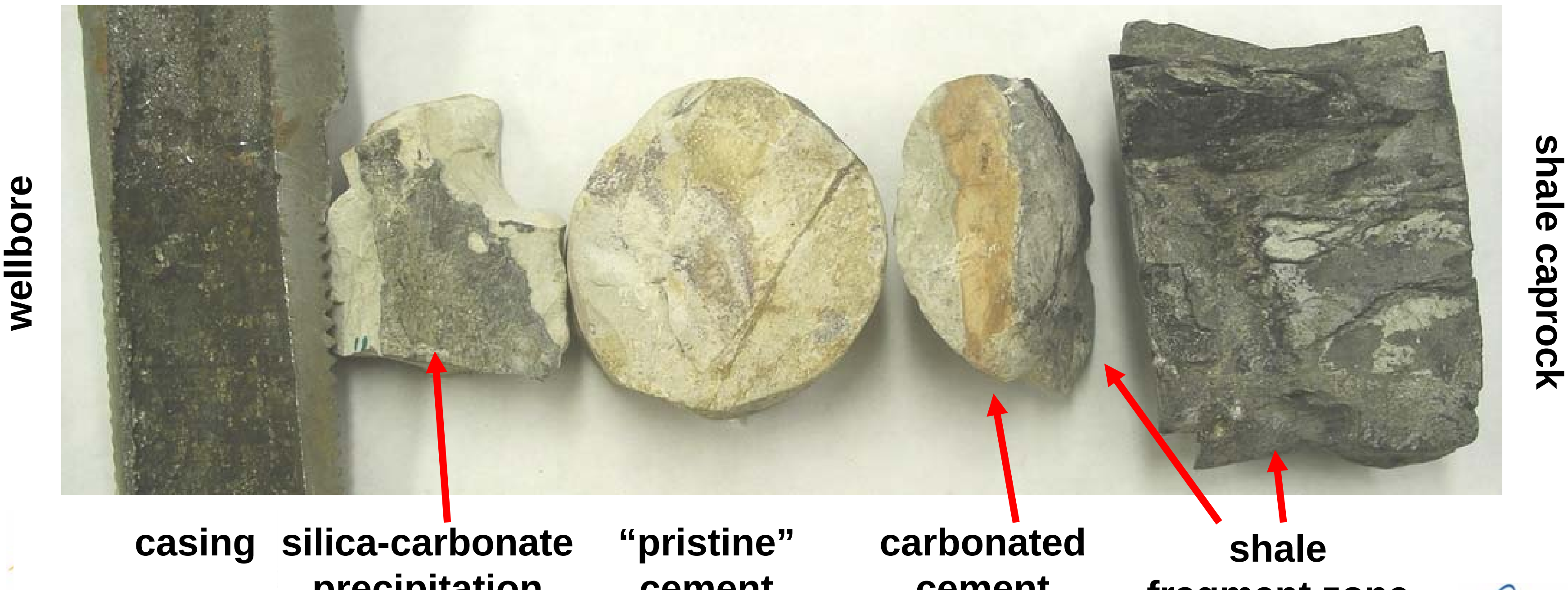
LA-UR-06-5429

Carey et al., 2005, *SPE*; Guthrie et al., 2005, Midland CO_2 Conf.

Cement sample from SACROC 49-6 (6550' near top of pay) was exposed to CO_2 for ~ 30 years (~110,000 tonnes).

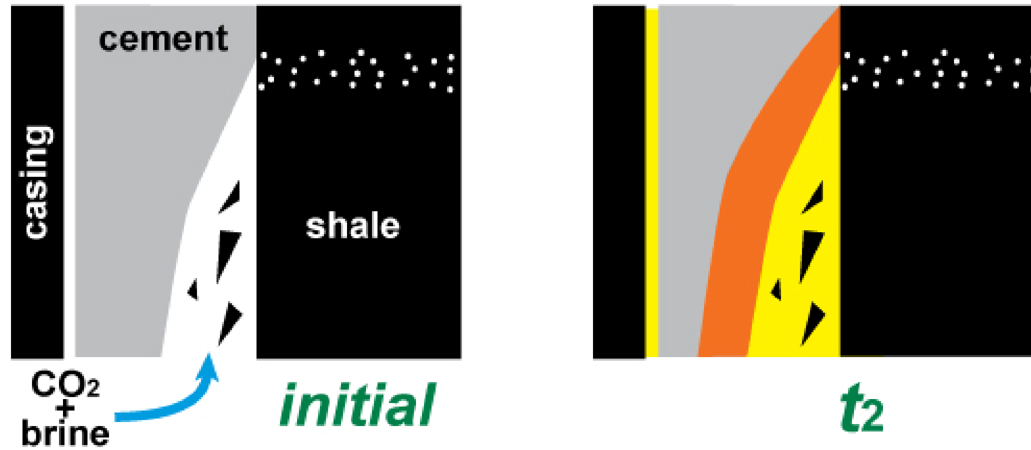
- "pristine" hydrated cement, containing portlandite ($Ca(OH)_2$) both in matrix and in veins➔precludes complete dissolution & Gasda et al. mechanisms C&E
- thin carbonated zone between cement and casing (Gasda et al. mechanism A)
- orange carbonated cement ("popcorn" texture) (Gasda et al. mechanism F)
- gray carbonated vein➔fluid flow followed by precipitation of silica/carbonate



Carey et al., 2007, *Int. J. GHG Control*, 1:75-85

Observations suggest initial flow along interfaces followed by precipitation of silica and carbonate phases.

- **fluid flow along interface into sandy unit in shale**
- **carbonation of cement to form orange zone**
- **precipitation of silica and carbonate from brine in “yellow” zones**

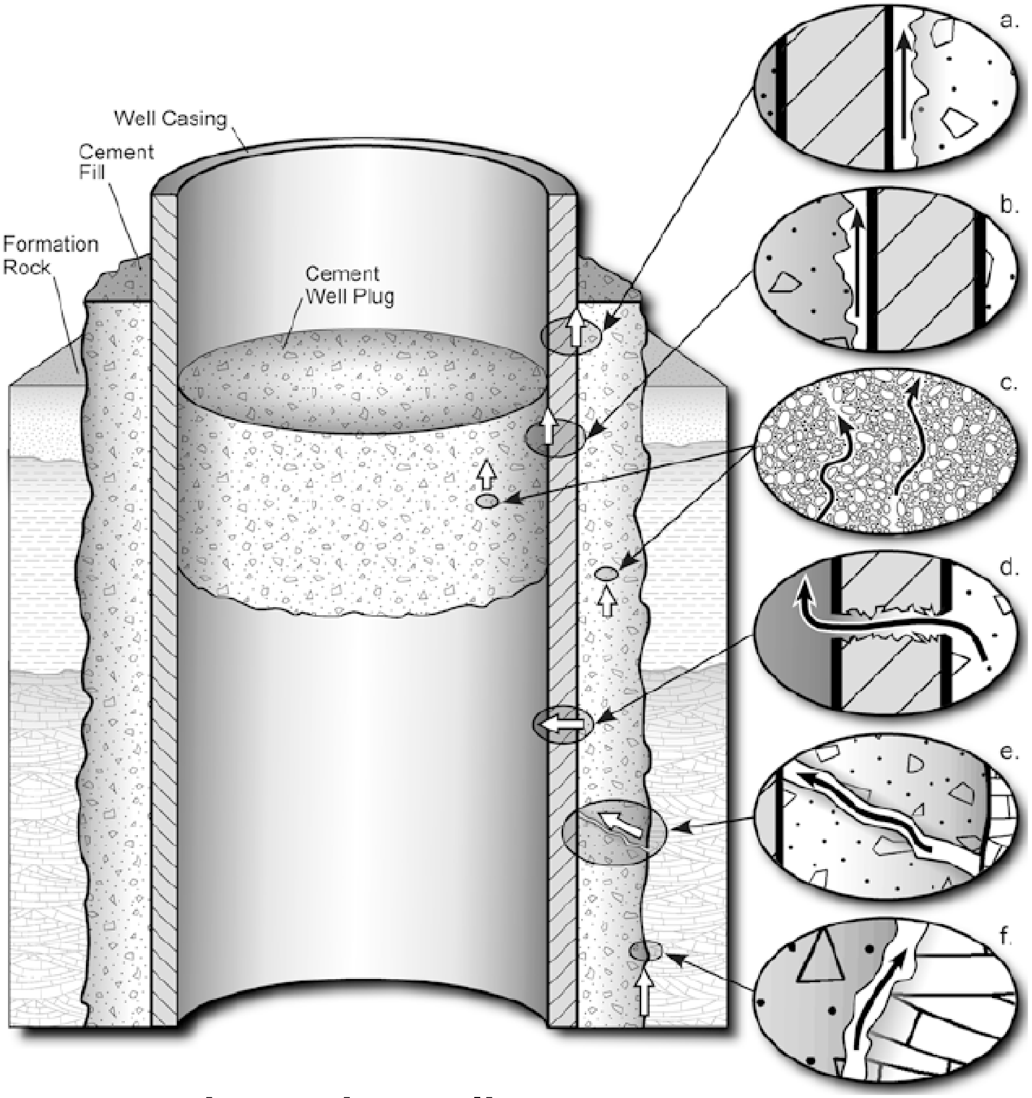


wellbore

shale caprock

casing | **silica-carbonate precipitation** | **“pristine” cement** | **carbonated cement** | **shale fragment zone**

Summary of major processes occurring at wellbore 49-6.



0. ~~dissolution/corrosion of cement~~

1. **flow between cement & casing (Gasda et al. mechanisms A & B)**
   - precipitation along interface

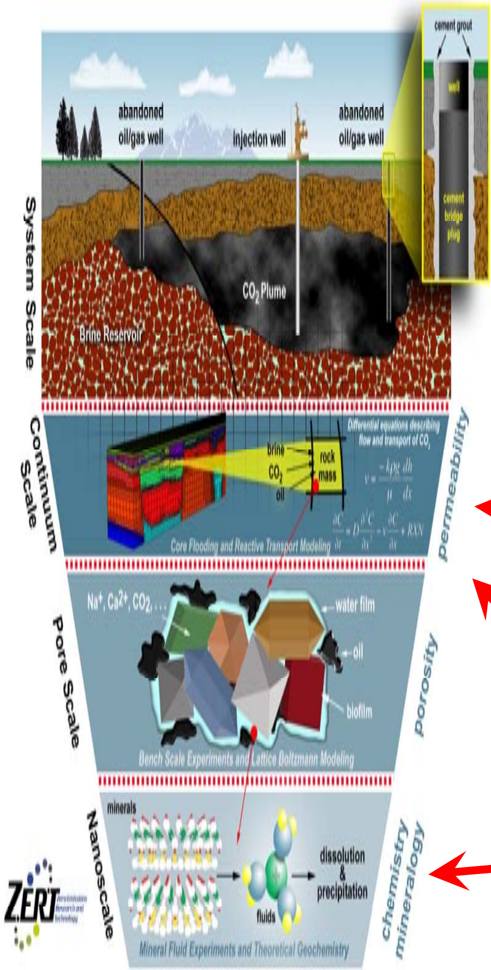
2a. **diffusion through cement (Gasda et al. mechanism C)**
   - minimal—$Ca(OH)_2$ preserved

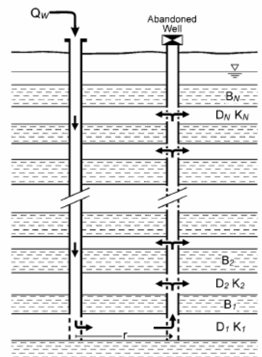
2b. **fracture flow through cement (Gasda et al. mechanism E)**
   - minimal—$Ca(OH)_2$ along fractures

3. **flow between cement & shale (Gasda et al. mechanism F)**
   - cement alteration;
   - precipitation filling voids

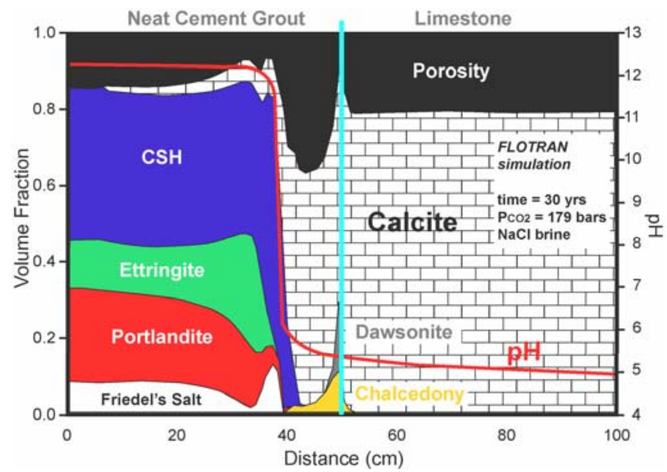
Gasda, Bachu, Celia, 2004
Princeton CMI

Using EOR Experience to Develop a Multiscale Model for the Role of Cement Integrity in a CO_2 System





Semi-analytical model
for wellbore release
(LANL team w/ Princeton CMI)



predictive modeling of cement-CO2 reactions and rates
(Carey and Lichtner, in press; LANL)

EOR (SACROC)

experiment (M. Wigand, LANL)

observations and experiments to determine reactions, rates, & impact
(LANL and NETL)

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